Fitness tracking reveals task-specific associations between memory, mental health, and exercise

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Abstract

Physical exercise can benefit both physical and mental well-being. Different forms of exercise (i.e., aerobic versus anaerobic; running versus walking versus swimming versus yoga; high-intensity interval training versus endurance workouts; etc.) impact physical fitness in different ways. For example, running may substantially impact leg and heart strength but only moderately impact arm strength. We hypothesized that the mental benefits of exercise might be similarly differentiated. We focused specifically on how different forms of exercise might related to different aspects of memory and mental health. To test our hypothesis, we collected nearly a century's worth of fitness data (in aggregate). We then asked participants to fill out surveys asking them to self-report on different aspects of their mental health. We also asked participants to engage in a battery of memory tasks that tested their short and long term episodic, semantic, and spatial memory. We found that participants with similar exercise habits and fitness profiles tended to also exhibit similar mental health and task performance profiles.

Introduction

Engaging in physical activity (exercise) can improve our physical fitness by increasing muscle strength (Crane et al., 2013; Knuttgen, 2007; Lindh, 1979; Rogers and Evans, 1993), increasing bone density (Bassey and Ramsdale, 1994; Chilibeck et al., 2012; Layne and Nelson, 1999), increasing cardiovascular performance (Maiorana et al., 2000; Pollock et al., 2000), increasing lung capacity (Lazovic-Popovic et al., 2016) (although see Roman et al., 2016), increasing endurance (Wilmore and Knuttgen, 2003), and more. Exercise can also improve mental health (Basso and Suzuki, 2017; Callaghan, 2004; Deslandes et al., 2009; Mikkelsen et al., 2017; Paluska and Schwenk, 2000; Raglin, 1990; Taylor et al., 1985) and cognitive performance (Basso and Suzuki, 2017; Brisswalter et al., 2002; Chang et al., 2012; Etnier et al., 2006).

The physical benefits of exercise can be explained by stress-responses of the affected body tissues. For example, skeletal muscles that are taxed during exercise exhibit stress responses (Morton et al., 2009) that can in turn affect their growth or atrophy (Schiaffino et al., 2013). By comparison, the benefits of exercise on mental health are less direct. For example, one hypothesis is that exercise leads to specific physiological changes, such as increased aminergic synaptic transmission and endorphin release, which in turn act on neurotransmitters in the brain (Paluska and Schwenk, 2000).

Speculatively, if different exercise regimens lead to different neurophysiological responses, one might be able to map out a spectrum of signalling and transduction pathways that are impacted by a given type, duration, and intensity of exercise in each brain region. For example, prior work has shown that exercise increases acetylcholine levels, starting in the vicinity of the exercised muscles (Shoemaker et al., 1997). Acetylcholine is thought to play an important role in memory formation (Palacios-Filardo et al., 2021, e.g., by modulating specific synaptic inputs from entorhinal cortex to the hippocampus, albeit in rodents;). Given the central role of these medial temporal lobe structures play in memory, changes in acetylcholine might lead to specific changes in memory formation and retrieval.

In the present study, we hypothesize that (a) different exercise regimens will have different, quantifiable impacts on cognitive performance and mental health, and that (b) these impacts will be consistant across individuals. To this end, we collected a year of fitness tracking data from each of 113 participants. We then asked each participant to fill out a brief survey in which they self-evaluated several aspects of their mental health. Finally, we ran each participant through a battery of memory tasks, which we used to evaluate their memory performance along several dimensions. We examined the data for potential associations between memory, mental health, and exercise.

Results

- exploratory analysis (correlations)
  - Memory-memory
  - fitness-fitness
  - survey-survey
  - (fitness + survey)-memory
- predictive analysis (regressions)
  - Predict memory performance on held-out task from other tasks
  - Predict memory performance on each task using fitness data
  - Predict memory performance on each task using survey data
- Reverse correlations: look at recent changes versus baseline trends
  - Fitness profile that predicts performance on each task (barplots + timelines)
  - Fitness profile for each survey demographic (barplots + timelines)
    - Select out mental health demographics (based on meds, stress levels)

Discussion

- summarize key findings
- correlation versus causation
- what can vs. can't we know? we can identify correlations, but not causal direction– e.g. we cannot know whether exercise *causes* mental changes versus whether people with particular neural profiles might tend to engage in particular exercise behaviors. that being said, we *can* separate out baseline tendencies (e.g., how people tend to exercise in general) versus recent changes (e.g., how they happened to have exercised prior to the experiment).
- related work (exercise/memory, exercise/mental health), what this study adds
- future direction: towards customized physical exercise recommendation engine for optimizing mental health and mental fitness

Methods

We ran an online experiment using the Amazon Mechanical Turk platform. We collected data about each participant's fitness and exercise habits, a variety of self-reported measures concerning their mental health, and about their performance on a battery of memory tasks. We mined the dataset for potential associations between memory, mental health, and exercise.

Experiment

Participants

We recruited experimental participants by posting our experiment as a Human Intelligence Task (HIT) on the Amazon Mechanical Turk platform. We limited participation to Mechanical Turk Workers who had been assigned a "Masters" designation on the platform, given to workers who score highly across several metrics on a large number of HITs, according to a proprietary algorithm managed by Amazon. We further limited our participant pool to participants who self-reported that they were fluent in English and regularly used a Fitbit fitness tracker device. A total of 160 workers accepted our HIT in order to participate in our experiment. Of these, we excluded all participants who failed to log into their Fitbit account (giving us access to their anonymized fitness tracking data), encountered technical issues (e.g., by accessing the HIT using an incompatible browser, device, or operating system), or who ended their participation prematurely, before completing the full study. In all, 113 participants remained that contributed usable data to the study.

For their participation, workers received a base payment of \$5 per hour (computed in 15 minute increments, rounded up to the nearest 15 minutes), plus an additional performance-based bonus of up to \$5. Our recruitment procedure and study protocol were approved by Dartmouth's Committee for the Protection of Human Subjects.

Gender, age, and race. Of the 113 participants who contributed usable data, 77 reported their gender as female, 35 as male, and 1 chose not to report their gender. Participants ranged in age from 19–68 years old (25$^{\text{th}}$ percentile: 28.25 years; 50$^{\text{th}}$ percentile: 32 years; 75$^{\text{th}}$ percentile: 38 years). Participants reported their race as White (90 participants), Black or African American (11 participants), Asian (7 participants), Other (4 participants), and American Indian or Alaska Native (3 participants). One participant opted not to report their race.

Languages. All participants reported that they were fluent in either 1 and 2 languages (25$^{\text{th}}$ percentile: 1; 50$^{\text{th}}$ percentile: 1; 75$^{\text{th}}$ percentile: 1), and that they were "familiar" with between 1 and 11 languages (25$^{\text{th}}$ percentile: 1; 50$^{\text{th}}$ percentile: 2; 75$^{\text{th}}$ percentile: 3).

Reported medical conditions and medications. Participants reported having and/or taking medications pertaining to the following medical conditions: anxiety or depression (4 participants), recent head injury (2 participants), high blood pressure (1 participant), bipolar (1 participant), hypothyroidism (1 participant), and other unspecified medications (1 participant). Participants reported their current and typical stress levels on a Likert scale as very relaxed (-2), a little relaxed (-1), neutral (0), a little stressed (1), or very stressed (2). The "current" stress level reflected participants' stress at the time they participated in the experiment. Their responses ranged from -2 to 2 (current stress: 25^{th} percentile: -2; 50^{th} percentile: -1; 75^{th} percentile: 1; typical stress: 25^{th} percentile: 0; 50^{th} percentile: 1; 75^{th} percentile: 1). Participants also reported their current level of alertness on a Likert scale as very sluggish (-2), a little sluggish (-1), neutral (0), a little alert (1), or very alert (2). Their responses ranged from -2 to 2 (25^{th} percentile: 0; 50^{th} percentile: 1; 75^{th} percentile: 2). Nearly all (111 out of 113) participants reported that they had normal color vision, and 15 participants reported uncorrected visual impairments (including dyslexia and uncorrected near- or far-sightedness).

Residence and level of education. Participants reported their residence as being located in the suburbs (36 participants), a large city (30 participants), a small city (23 participants), rural (14 participants), or a small town (10 participants). Participants reported their level of education as follows: College graduate (42 participants), Master's degree (23 participants), Some college (21 participants), High school graduate (9 participants), Associate's degree (8 participants), Other graduate or professional school (5 participants), Some graduate training (3 participants), or Doctorate (2 participants).

Reported water and coffee intake. Participants reported the number of cups of water and coffee they had consumed prior to accepting the HIT. Water consumption ranged from 0–6 cups (25^{th} percentile: 1; 50^{th} percentile: 3; 75^{th} percentile: 4). Coffee consumption ranged from 0–4 cups (25^{th} percentile: 0; 50^{th} percentile: 1; 75^{th} percentile: 2).

Tasks

Upon accepting the HIT posted on Mechanical Turk, the worker was directed to read and fill out a screening and consent form, and to share access to their anonymized Fitbit data via their Fitbit account. After consenting to participant and successfully sharing their Fitbit data, participants filled out a survey and then engaged in a series of memory tasks.

Survey questions. We collected the following demographic information from each participant: their birth year, gender, highest (academic) degree achieved, race, language fluency, and language familiarity. We also collected information about participants' health and wellness, including about their vision, alertness, stress, sleep, coffee and water consumption, location of their residence, activity typically required for their job, and exercise habits.

Free recall.

Naturalistic recall.

Foreign language flashcards.

Spatial learning.

Fitness tracking using Fitbit devices

Processing Fitbit data

Raw metrics.

Comparing recent versus baseline measurements.

Exploratory correlation analyses

Imputation and interpolation of missing data.

Regression-based prediction analyses

Reverse correlation analyses

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Data and code availability

All analysis code and data used in the present manuscript may be found here.

Author contributions

Concept: J.R.M. Experiment implementation and data collection: G.M.N. Analyses: G.M.N., E.C., P.C.F., and J.R.M. Writing: J.R.M.

Competing interests

The authors declare no competing interests.

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